REPORT OF SURVEY CONDUCTED AT

NORTHROP

AIRCRAFT DIVISION

HAWTHORNE, CALIFORNIA

MARCH 1989

DoD 4245.7-M

"TRANSITION FROM DEVELOPMENT TO PRODUCTION"

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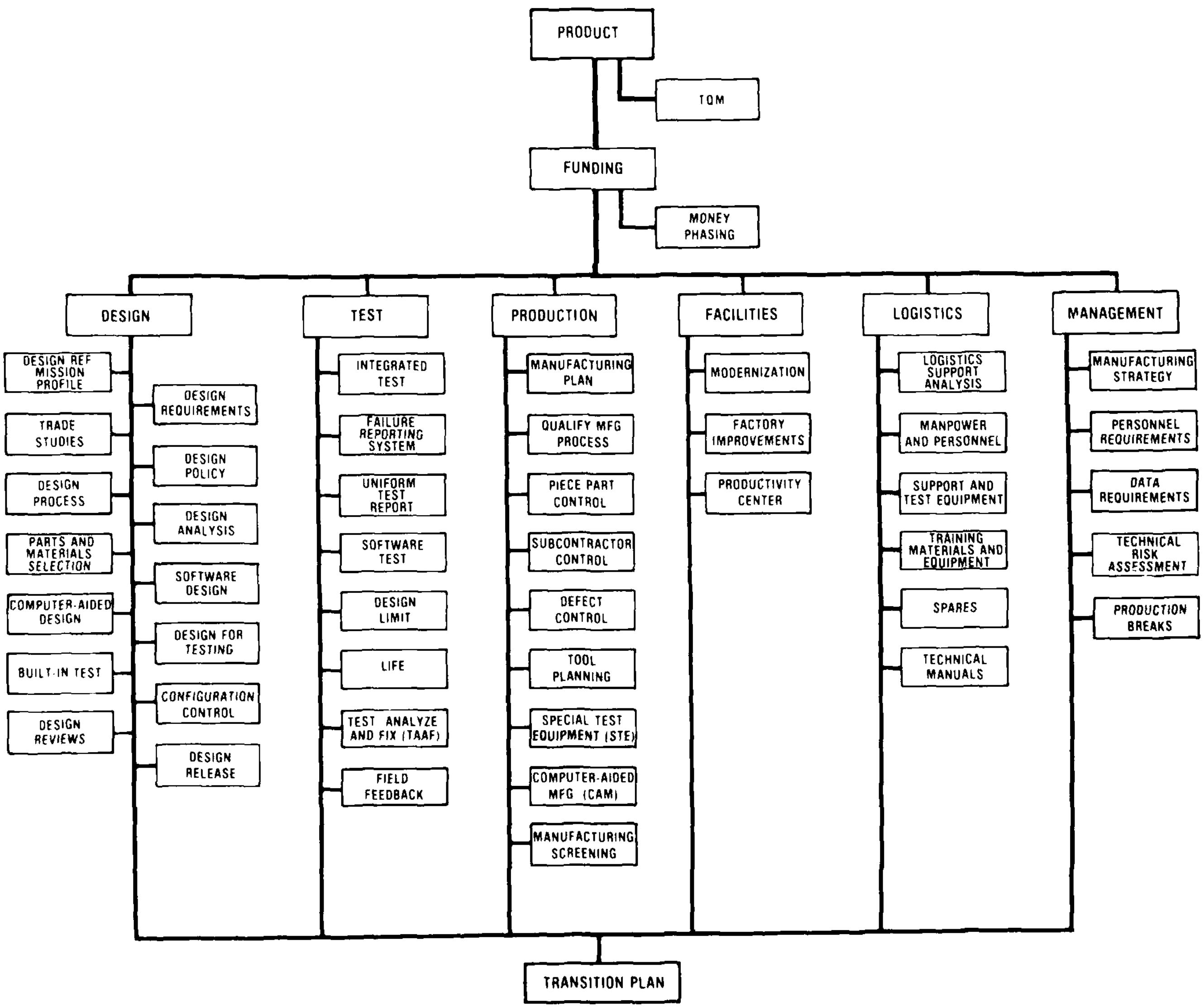

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The purpose of the Best Manufacturing Practices (BMP) survey conducted at this facility was to identify their best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout the U.S. industrial base. The actual exchange of detailed data will be between contractors at their discretion. ~~A company~~ point of contact ~~is listed~~ in the report

The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry.

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SECTION 1

EXECUTIVE SUMMARY

The Best Manufacturing Practices (BMP) team conducted a survey at Northrop Aircraft Division (NAD). The purpose of the survey was to review and document the best practices and potential industry-wide problems at NAD. The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry. The team surveyed the NAD facilities located in Hawthorne, California.

1.1 KEY FINDINGS

There were many best practices observed at NAD that are detailed in this report. Some of the more significant findings included in this report are summarized below:

Item	Page
Phased Parallel Release Introduces manufacturing, materiel, quality assurance, and logistics support considerations into the front-end of the design process.	8
Computerized Design Analysis The integration of several computerized design analysis tools is described.	9 - 10
Integrated Planning and Control for Assembly System The trouble-free implementation of a paperless shop-floor control system is described.	14
Fabrication of Tooling from Three-Dimensional Design Data This technology reduces lead time and costs and increases accuracy of production tooling.	19
Composites Fabrication Innovative techniques in the use of tooling for composites are described.	16, 17 & 20
Proven Process Laboratory Manufacturing processes are designed and developed in the laboratory and then documented in a process specification prior to release.	16
Multi-Axis Computer Aided Manufacturing Provides an effective method for developing and proving out NC program code and programming techniques.	22

Coordinate Measuring Machine (CMM) Technology 22
A recent CMM implementation utilizes state-of-the-art equipment

Northrop Aircraft Division Strategic Architecture Plan 30
A strategic plan that ensures that all future investments in improved technology conform to an overall corporate architecture, regardless of ROI considerations.

SECTION 2

INTRODUCTION

2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) survey conducted at Northrop Aircraft Division (NAD) was to identify best practices, review manufacturing problems and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout industry. The ultimate goal of the BMP program is to reduce the life cycle cost of defense systems and strengthen the U.S. industrial base by using these techniques and technologies to solve manufacturing problems and improve quality and reliability.

To accomplish this goal, a team of Navy engineers supported by representatives of the Army and the Department of Commerce accepted an invitation from NAD to review and document the most advanced manufacturing processes and techniques used in their facilities located in Hawthorne, California. The survey was conducted on March 27-31, 1989 by the team identified in Appendix B of this report.

The results of BMP surveys are entered into a database to track the best practices available in industry as well as common manufacturing problems identified by industry. The information gathered is available for dissemination through an easily accessible computer database. The actual exchange of detailed technical data will take place between contractors at their discretion on a strictly voluntary basis.

The results of this survey should not be used to rate NAD among other defense contractors. A contractor's willingness to participate in the BMP program and the results of a survey have no bearing on one contractor's performance over another's. The documentation in this report and other BMP reports is not intended to be all inclusive of a contractor's best practices or problems. Only selected non-proprietary practices are reviewed and documented by the BMP survey team.

2.2 SURVEY PROCESS

This survey was performed under the general survey guidelines established by the Department of the Navy. The survey concentrated on the functional areas of design, test, production, facilities, logistics and management. The team evaluated NAD's policies, practices and strategies in these areas. Furthermore, individual practices reviewed were categorized as they relate to the critical path templates of DOD 4245.7-M, "Transition From Development To Production." NAD identified potential best practices and potential industry-wide problems. These practices and problems and other areas of interest identified were discussed, reviewed, and documented for dissemination throughout the U.S. industrial base.

The format for this survey consisted of formal briefings and discussions on best practices and problems. Time was spent on the factory floor reviewing practices, processes, and equipment. In-depth discussions were conducted to better understand and document the practices and problems identified.

2.3 NAVY CENTERS OF EXCELLENCE

Demonstrated industry wide problems identified during the Best Manufacturing Practices surveys may be referred to one of the Navy's Centers of Excellence. They are:

Automated Manufacturing Research Facility (AMRF)
Gaithersburg, MD

Applied research in the machining processes, within a heterogeneous computer integrated manufacturing environment

Electronics Manufacturing Productivity Facility (EMPF)
Ridgecrest, CA

Applied research in the processes and materials involved in the manufacture of circuit card assemblies

Metalworking Technology, Incorporated (MTI)
Johnstown, PA

Applied research in the metalworking processes

2.4 NORTHROP AIRCRAFT DIVISION OVERVIEW

The Aircraft Division of the Northrop Corporation is headquartered in Hawthorne, California. Nearly eight million square feet of facilities on 742 acres, both in Hawthorne and in several surrounding communities, are dedicated to the production of commercial and military aerospace products. The Division functions as a weapons systems prime contractor, associate contractor, and subcontractor.

The Aircraft Division employs over 15,000 personnel at its various locations. Production of 3,806 F-5/T-38 aircraft has just ended after nearly 30 years. The Division is the prime contractor and is teamed with McDonnell Douglas to build the YF-23 as part of the Advanced Tactical Fighter (ATF) aircraft program. The Division is the principal subcontractor to McDonnell Douglas with responsibility for the center and aft fuselage of the F/A-18 Hornet aircraft. The high degree of computerization has made it possible to produce these aircraft on a paperless assembly line. The Division also fabricates and assembles a 153 foot section of fuselage for the Boeing 747 aircraft, having participated since program inception.

An essential part of the Division's work is carried out in the $50 million Integrated Systems Simulation Laboratory (ISSL) where weapons systems requirements are validated, designs evaluated, and operational tactics refined in a very high fidelity simulation. Facilities to support advanced programs include a 320,000 square foot advanced composites facility with autoclaves capable of handling components up to 46 feet long and 15 feet in diameter.

The Ventura unit of the Aircraft Division, which was not part of the survey, has facilities in Newbury Park, California, and Perry, Georgia for research, design, and production of unmanned air vehicles. The Newbury Park complex consists of about 700,000 square feet of buildings on 50 acres, while the new facility located in Georgia has 741,000 square feet on 200 acres.

The Ventura unit, the world's largest manufacturer of unmanned aircraft, currently produces the Chukar III target drone and the Chukar IIIR reconnaissance drone. The unit is also the prime contractor for the AGM-136 Tacit Rainbow defense suppression missile.

2.5 ACKNOWLEDGEMENTS

Special thanks are due to all the people at NAD whose participation made this survey possible. In particular, the BMP team acknowledges the special efforts of Mr. Jim Hoover. His enthusiastic support of the BMP team, both prior to and during the survey, contributed to the success of this survey and was deeply appreciated by the team.

2.6 NORTHROP AIRCRAFT DIVISION POINT OF CONTACT

While the information included in this report is intended to be descriptive of the best processes and techniques observed at NAD, it is not intended to be all inclusive. It is anticipated that the reader will need more detailed data for a true technology transfer to occur. The reader is encouraged to contact NAD directly for the purpose of sharing or transferring technology. Any exchange of technology resulting from such a contact is strictly voluntary and at the discretion of NAD.

The NAD point of contact for the Best Manufacturing Practices Program is:

Northrop Corporation
Aircraft Division
Attn: Mr. Jim Hoover, Vice President
One Northrop Avenue, V5080/04
Hawthorne, CA 90250
Telephone: (213) 332-6612

SECTION 3

BEST PRACTICES

3.1 DESIGN

PRODUCT DEFINITION DEVELOPMENT CENTER

The NAD Product Definition Development Center (PDDC) is the element of the Northrop Aircraft Division Strategic Architecture Plan (NADSARP) that fully defines the weapon system from a common database, providing the product definition, product delivery, and product support processes with simultaneous access to product information.

PDDC is a major change in the processes of design, planning, manufacturing, and support of a weapon system. It is organized by process, not by function, into small teams, each responsible for completely defining a portion of the product and the processes to be used to build and support that portion of the product. It is critically dependent upon working with three-dimensional (3-D) computer aided design (CAD) and product information data in an integrated environment for shared data and communication. It is almost equally dependent upon the co-location of program teams to generate an interactive process among designers, product support, quality assurance, configuration control, material planning, fabrication, assembly planning, tool engineering, and test and evaluation personnel.

The work flow will follow a phased parallel release plan to expedite functions which were previously in a serial schedule time plan. Both time and costs are projected to be reduced by 30% with the PDDC approach. NAD anticipated that design changes after release will be reduced by 75%, inventory will be reduced by 50%, and direct labor will be reduced by 25%.

This approach also facilitates product information transfer to the customer in conformance to the DOD Computer-Aided Acquisition and Logistics Support (CALS) program. The ATF prototype has utilized the PDDC methodology of a full 3-D defined product, and co-location and has established positive evidence of success. The ATF full scale development program is the selected program for transition to full implementation.

PDDC requires a shared database. A project to structure, manage, and implement access and communication, not only within NAD, but also with the contractor and customer community, is scheduled to be completed by 1990. Both geometric Northrop Computer Aided Design (NCAD) and business data are included in the database. Engineering data, configuration management and geometric data, weights analysis information, and work-in-process (WIP) data are included within the PDDC shared database. Additional functions, such as tool planning, material lists and planning, fabrication assembly planning, and test information, are in the process of being added. The PDDC database program is scheduled to be complete and fully operational by the end of 1990.

PHASED PARALLEL RELEASE SYSTEM

Decades ago, all the people involved in designing an airplane could work together under one roof. Since then, the complex requirements have caused enormous growth in design teams resulting in specialization, physical separation, and dispersion of the design team. The processes of design, manufacturing, and support were primarily manual and slow in responding to changes. Information passed on paper allowed errors to propagate. Design flaws would not be detected until late in the program, requiring a much higher cost to correct.

The purpose of the Phased Parallel Release System (PPRS) is to introduce considerations of manufacturing, materiel, quality assurance, and logistics support into the front end of the design process, along with engineering. The PPRS is currently supported by ARTEMIS software, which is supplied by METIER Corporation. The basic concept of PPRS is to co-locate members of the various disciplines as a product definition team to collectively and in parallel develop, exchange, investigate, and completely define the data required to produce the desired product. The system encourages the team concept of design and problem solving. The ARTEMIS software provides a clear and concise management tool to evaluate the status of program schedules.

This team approach to phased parallel release has allowed changes to be made more quickly, decreased errors, simplified or eliminated mockups, and reduced the time required for numerical control programming. NAD estimates an average savings of 30% over the serial release method.

RAPID MULTI-DISCIPLINARY COMPUTATIONAL METHODS

The Rapid Multi-Disciplinary Computational Methods Program (RAMCOMP) is implementing a unified computer based analysis system for aerosciences, flight controls, flight loads, mass properties, structural design/analysis, and structural dynamics.

The system ties the graphics created on the NCAD system to a variety of analysis software packages through the Northrop Computer Aided Structural Analysis (NCASA), which is a common pre- and post-processing software for all of the analysis tools used by NAD. These tools include NASTRAN (a commercial finite element analysis program) for stress/dynamics, Northrop Integrated Maneuver Loads Analysis Procedure (NORLOADS) for flight loading, Chrysler Improved Numeric Differencing Analyzer (CINDA) (a public domain finite difference thermal analysis program) for thermal analysis, and Automated Structural Optimization System (ASTROS) for structural analysis.

The benefits offered by this system is a standardized, consistent analysis procedure and a minimum of duplication of effort.

NORTHROP INTEGRATED MANEUVER LOADS ANALYSIS PROCEDURE

Northrop Integrated Maneuver Loads Analysis Procedure (NORLOADS) is an internally developed computer program for predicting structural design loads on maneuvering aircraft. The system uses subsonic and supersonic panel aerodynamics to calculate loads. Pressure distribution acquired by tests or calculation can be substituted for the panel aerodynamic calculations.

An interface between NORLOADS and NASTRAN has been created. This interface permits the aerodynamic loading calculator with NORLOADS to be fed directly into a NASTRAN model for calculation of deflection.

The NORLOADS graphics post processor provides information on:

* Aero geometry
* Stability coefficients
* Trim forces
* Trim pressure
* Loads integration
* Loads versus time plots
* Maneuver transient response data

NORLOADS can also utilize flight control software when applicable.

THERMAL ANALYSIS

NAD has developed an extensive thermal analysis capability based on CINDA and other programs, which offers a great deal of versatility. However, these programs require a great deal of tedious preparation in calculating thermal resistances.

NAD has developed software which automates much of the problem preparation for CINDA. Application of these procedures results in approximately 50% time savings over manual methods. Graphical depictions of the analysis results are also made possible by the NCASA software.

AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM

The Automated Structural Optimization System (ASTROS) is an integrated software system developed by NAD while under contract to the Air Force for use in the preliminary design of aerospace structures. The core of the ASTROS procedure is finite element structural analysis augmented by static and dynamic aerodynamic analyses and mathematical optimization techniques. Design constraints considered include static stress, strain displacement, modal frequency, and static/dynamic aeroelastic constraints.

ASTROS has provided an improved structural design in less time than is currently needed. The use of this automated design tool allows the designer to balance the structure's strength and stiffness while exploiting the benefits of anisotropy such as aeroelastic tailoring. The use of this single tool brings a focus to the design team, which improves its insight into the overall task. It is especially effective on composite materials.

ASTROS was delivered to the Air Force in July 1988 and is available to all interested parties through the Air Force Wright Aeronautical Laboratories in Dayton, Ohio. Northop is also involved as a subcontractor in an Air Force contract to enhance the capability of ASTROS.

VULNERABILITY ASSESSMENT AND DESIGN HARDENING

Recent changes have mandated that all major weapons systems pass a live fire test using munitions that are anticipated in combat. Testing must be passed and any required modification must be incorporated into the system prior to full scale development. To achieve this goal and reduce the risk in the live fire test, NAD has developed a software program called FASTPATCH, which allows the designers to evaluate vulnerability during the concept phase of the design and to make hardening an integral part of the design.

FASTPATCH takes the NCAD configurations, superimposes a 3" x 3" grid on the 3-D model, randomly locates shot lines through each grid section, and lists all components hit by each shot line. The system then repeats the process on an additional 25 views. FASTPATCH, when used in conjunction with NCAD, provides an extremely fast and accurate technique to assess the vulnerability of various sections of the aircraft to battle damage. This data is then analyzed in conjunction with the available missile fuzing data and detonation envelopes to position the internal components to achieve hardening with a minimal addition of weight.

FASTPATCH is a breakthrough software package which automates the vulnerability assessment, providing a fast, economical, accurate, and powerful tool for hardening the aircraft design.

LOW OBSERVABLES TECHNOLOGY

NAD has developed Radar Cross Section (RCS) computer codes for analysis and prediction of RCS signatures to a high degree of sophistication. Programs for high, medium, and low frequencies exist.

The high frequency analysis is the basic analysis area covering vehicle shaping, duct scattering, and shaping and full vehicle prediction. In the medium frequency range, edge scattering and spike width control, plus full metal wing prediction provide refinements of the signature characteristics. Another significant refinement is the analysis of steps, cracks, gaps, and bumps in the low frequency area. The approach to the RCS analysis has been developed to optimize the use of the computer analysis in a reasonable quantity of computer processing. Experimental and prototype tests and measurements are correlated with the computer-based predictions.

To complete the low observable design, the infrared signature, visual, laser, and acoustic signatures are also analysed and measured. The infrared signature prediction and design have also been developed into an analytical computer-based process, significantly related to heat transfer and diffusion technology.

These analysis processes have been made more efficient by utilizing the NCAD geometric database for creation of pre- and post-processing tasks.

GLOBAL COMPOSITES WEIGHT REDUCTION CONCEPT

NAD has implemented a weight reduction concept for composite structures, which examines the whole structure rather than minute pockets of laminates and scalloping of flange trim. The concept is to delete entire plies, fasteners, and doubler pad-ups and to integrate smaller details into a larger part. These larger parts offer a reduction in weight while retaining or improving producibility.

NAD is also resizing entire laminates during the detail design stages based on load requirements and proven part characteristics. Normally, design changes are resisted at this point due to the tooling changes required. However, NAD uses its capabilities in 3-D part data and direct numerical control (DNC) machining to retool efficiently at these early design stages.

This concept has been implemented on B-2 large integrally stiffened skins and on selected YF-23 parts. Benefits have been lower cost, lower weight, and reduced part complexity.

DIGITAL PRODUCT MODEL

The Digital Product Model (DPM) is an Air Force funded program to create a product model with complete digital description of geometry and associated data to comply with DOD-STD-100 requirements. This product model will be able to be exchanged digitally and be used as a shared database among different systems. The Air Force program is a proof of concept for the evolving Product Data Exchange Specification (PDES).

At the time of the survey, the 3-D data modeling of geometry and topology had been completed. Software for laminated structures, standard parts, features, and a parametric evaluator are partially functional. The parametric evaluator software is effective at verifying the accuracy of the data exchange process and is particularly significant for 3-D surfaces. Completion of the software and demonstration of the data transfer and database sharing are planned for 1989. A demonstration workshop is scheduled for August 1989. Selected product models of the ATF will be transmitted utilizing PDES level 2.

The demonstration on the ATF is also planned to include a tree structured data management feature, potentially based on Oracle database software running on personal computers and mainframes. An additional feature will be a neutral 2-D extract that is needed to interface with the subcontractor community.

NORTHROP COMPUTER-AIDED DESIGN

NCAD is a 3-D integrated CAD process. It provides several benefits, such as shorter preparation time for a descriptive model that provides a shared database for automated manufacturing and analysis. The ATF program provided the demonstration and validation of the NCAD capability and benefits. Benefits are shorter drawing preparation time, improved fit at assembly associated with significant reduction in shimming labor, quality assurance costs and maintenance of a current configuration database, and reduction of non-value added functions and errors. Approximately 20% of errors could be traced to the two-dimensional (2-D) drafting process of dimensioning, essentially eliminated via the 3-D database process.

Other benefits gained from NCAD integration with analysis and automated manufacturing are the increased ability to perform concurrent design and manufacturing planning processes and the improvement in communication resulting from co-locating personnel from design and manufacturing.

THREE-DIMENSIONAL TO TWO-DIMENSIONAL EXTRACTION

Advanced aircraft programs require the geometric capabilities of a 3-D CAD system to accurately define complex part geometry. Traditional part fabrication operations frequently require 2-D geometric representations of parts. In the past, this requirement has been satisfied by the creation of a 2-D database in parallel with the 3-D database. This is redundant and, due to inconsistencies between the two databases, can be inaccurate if changes are not simultaneously incorporated in both.

The 2-D extract system, an option of NCAD, eliminates these problems by eliminating the redundant 2-D database. With this system, the part is dimensioned in the 3-D model. The datum planes and tolerances are also defined. Previously dimensioned geometry cannot be changed in the 3-D model without deleting the old dimensions and reinserting the new dimensions. This eliminates the configuration control problems, which were possible when two independent databases were being maintained.

Once the required dimensions are inserted into the 3-D database, the 2-D extract system automatically displays the multi-view 2-D drawings. The format of these views can be specified by the user.

INTEGRATED CONFIGURATION MANAGEMENT SYSTEM

The successful application of configuration management techniques is critical to any organization engaged in the design and manufacture of complex systems. By its nature, configuration management must be rigidly and accurately maintained since control is nearly impossible to regain once it is lost.

The Integrated Configuration Management System (ICMS) will provide a linkage between the various business, text, graphics, and geometry systems used by NAD. The system provides technical and administrative aids to control configuration and maintain a configuration history. The system also provides a process to verify that all requirements for product delivery are satisfied.

The ICMS is an automated system that utilizes a relational database. The system provides for on-line inquiries, data updating, and report generation. ICMS will utilize existing product configuration systems through integration and interfaces.

3.2 TEST

COORDINATED DESIGN AND MANUFACTURING TEST

NAD conducts coordinated, but separate testing for design validation and manufacturing risk reduction in the composites area prior to the start of detail design. Past practice typically used the same test article for both purposes in an attempt to reduce costs. NAD has found that this practice causes delays in the testing and generally does not provide adequate results for either area.

Design development and validation test articles can be developed in a simplified form to isolate specific conditions under investigation and to include special pad-ups and fixturing. The manufacturing risk reduction testing concentrates on areas of manufacturing complexity representing a production challenge.

NAD reports the following benefits resulting from early coordinated testing:

* Rapid fabrication, testing, and analysis of design test articles.
* More mature detail design.
* Rapid technology insertion.
* Improved first article yield.
* Better understanding of design requirements.
* Reduced nonconformance.
* Flatter production learning curve.

FLIGHT TEST AIRBORNE DATA SYSTEM

The NDS-3000 is a modular, distributed, digital flight test data acquisition system, which was designed and built by NAD for its in-house use. It has the added advantage of emulating the Air Force Flight Test Instrumentation System (AFFTIS), which is required by the Air Force for operation on its ranges. Since the system is modular, it can be configured to satisfy the specific flight test data requirements for each air frame being tested. Different modules can satisfy a wide variety of signal conditioning requirements, such as discretes, analog, and temperature, as well as bus interfaces for MIL-STD-1553, Aeronautical Radio, Inc. (ARINC) 429, and IEEE 488 buses. Gains, offsets, filter characteristics, and sample rates can be modified by reprogramming the system controller.

The NDS-3000 is an outgrowth of previous NAD data acquisition systems, the NDS-1000 and NDS-2000. Similar hardware is available commercially; however, it is subject to lead times as long as two years. By utilizing its in-house capabilities, NAD is able to have access to high quality hardware with lead times as low as one or two months.

ACOUSTIC TEST CHAMBERS

NAD has developed two unique acoustic test chambers to test aircraft components under severe environments. This test facility is notable because it provides the capability to superimpose an acoustic environment over normally tested environmental conditions, thus simulating actual flight conditions more accurately. The chambers each utilize either of the following acoustic generators: Team Corporation Mark VI or Norair Mark V. These generators were originally developed by NAD and are now manufactured under license by Team, Inc. They utilize high volume, high pressure air, which flows through a poppet valve modulated by a hydraulic actuator to generate the acoustic noise.

One chamber is configured to subject the test article to vibration and acoustic noise simultaneously. This chamber uses two Westeam 20,000 force-pounds generators for vibration excitation. The second chamber can subject the test article to temperatures as high as 1500°F and acoustic noise up to 174 db overall sound pressure level. In this configuration, test articles up to 20" x 20" can be tested.

The thermal chamber uses Research, Inc. model 28016 lamp assemblies powered by a Research, Inc. model 650 300 KW power supply as a heat source.

3.3 PRODUCTION

INTEGRATED PLANNING AND CONTROL FOR ASSEMBLY

In February 1989, NAD's F/A-18 final assembly line was converted to an entirely paperless manufacturing shop floor control system. The computerized system that manages the production line, Integrated Planning and Control for Assembly (IMPCA), was developed completely in-house at NAD. Due to the critical role of the system in the production process, 100% reliability was required for the IMPCA system. The system was constructed using a fault-tolerant approach on a Tandem computer system.

By converting to the IMPCA system, NAD was able to eliminate 16,000 pieces of paper per shipset. A total of 400,000 pieces of paper were eliminated at 104 stations in 14 cost centers on the line. The projected cost savings over the course of the F/A-18 contract are $20 million. The major functions performed by the system include:

* Work planning, instuction, and dispatching.
* Resource allocation.
* Work performance monitoring and evaluation.
* Maintenance of electronic records.

NAD believes that the system has improved the overall quality of the production process by providing real-time access to data. Approved users can get access to their data at any terminal. Many of the more mundane work assignments formerly performed by supervisors are now performed automatically by the system. Furthermore, management has better assurance that tasks are done in the proper order due to the monitoring capabilities of the system. New information is being gathered, which can be used to adjust time standards. Up-to-the-minute status information, which indicates the progress of jobs, is available on-line.

NAD's conversion plan was critical to the success of this program. Four key aspects of this plan were:

* Informing and educating affected employees.
* Development of prototypes and simulations for selected centers.
* Installation and transition without disruption to the line and the delivery schedule.
* Validation of the new system as functionally equivalent to the previous paper-driven one.

NAD recognized that perhaps the biggest obstacle to the implementation of the paperless system was employee acceptance. Fear of the system was overcome through briefings and training programs that began two years before the conversion. The system included user-developed guide screens that dealt in specific terms and methods familiar to the users. During the final stages of the education process, experienced users in each center conducted the hands-on training for their fellow employees. Acceptance of the system was so great that there were requests to abandon the paper-driven system prior to the end of the validation period.

During the conversion to the automated system, 15 shipsets were produced using both the paper-driven and the electronic methods. The first five of the 15 shipsets were used to introduce the staff to the system and were not a part of the validation process. The last ten were used by the Air Force Plant Representative Office (AFPRO) for in-depth validation of the new system. When minor discrepancies were found during validation, they were equally likely to be in the paper-driven system or the new one.

Figure 3.3-1: IMPCA Terminal on the Shop Floor

Several other key aspects of NAD's approach to the conversion problem contributed to its success. Three production work centers were simulated by the development staff to get a better understanding of shop floor activities. A change control team made up of users, data processing staff, manufacturing initiatives process staff, and project engineers had to approve all changes to the system. Any document in the system was owned by only one user at a particular time. A strict password and electronic-stamp security system is embedded within the system.

With each succeeding shipset produced in a paperless mode, NAD has become more confident with the IMPCA system and paperless manufacturing. Migration plans are currently being generated for the N-14, 747, B-2 and ATF programs.

PROVEN PROCESS LABORATORY

NAD has initiated an effort to increase product conformance and reduce engineering changes by providing complete, proven manufacturing process specifications to engineering and manufacturing organizations. This effort involves the establishment of a proven process laboratory, which is in early stage development. It will develop process designs that will be documented in specification form and then validated to become a Proven Production Process Specification (PPPS). A manufacturing process library will then be set up for access by engineering for use during product design. The PPPS would include a description of the fabrication process and identification of required resources, including training level necessary, process measurement requirements for process control, a range of conformance criteria limits, and data recording recommendations.

This methodology supports concurrent engineering principles with emphasis on process control. The basic concept is to move from an experience based manufacturing system to a fully documented knowledge based system. The "to be" manufacturing process technology information structure is being defined and will be based on a classification system structured by similar part types, material types, and manufacturing process types.

Current activity includes analysis of nonconformance in the fabrication, assembly, and test of composite components. A generic composites product manufacturing flow diagram has been developed and broken into sub-processes. Each sub-process is being illustrated and described in narrative form. In addition, capacity limits are being described, process control criteria are being defined, and data required for process control are being identified for each sub-process.

CONTROL OF NEXT ASSEMBLY FIT WITH CURE TOOLING

NAD has implemented a philosophy of building cure tooling, which precisely controls the mating surface for subsequent assemblies on selected F/A-18 and YF-23 composite parts.

Fabrication methods have traditionally driven the design of detail fabrication tooling. For example, "C" section spars are laid-up and cured on male tools which introduce variances on the outer part surfaces. These have to be absorbed during the spar-to-wing mechanical assembly process. This is traditionally accomplished by assembling the spar and wing, measuring gaps between the spar and wing, disassembling the parts, and applying a shim, which is either a liquid or a made-to-fit metal shim.

NAD's approach to this problem has been to build composite substructures, such as frames, longerous, ribs, and spars, so that the mating surface for the next assembly is controlled by the tooling. In the case of the "C" section spar, the approach would be to lay up the part in a female mold, resulting in an outer mold line surface, which is a precise fit to the next assembly operation and directly traceable to master loft data.

Fabricating parts in this manner is more difficult than on male tools and requires matched thermal expansion between the tool and the part. However, controlling the next assembly fit with the cure tooling has reduced assembly work because of the better fit. It has also provided better strength, improved fuel sealing, and improved waviness control. Another advantage of this technique is that tooling lead time has been reduced because only the mating surface features are required initially, thus shortening order lead times.

CONCURRENT CURING OF COMPOSITE ASSEMBLIES

NAD is using concurrent curing techniques to eliminate cumulative laminate thickness variability on B-2 and YF-23 composite structures.

Composite laminate thickness fluctuations are the result of raw material and fabrication process variables and are especially critical on thick laminates. Raw material variables, such as fiber areal weight, resin content, and fiber and resin density, coupled with fabrication process variables, such as resin leakage, fiber washout, and void content, can add up to a ±10% cumulative laminate thickness variation. Traditionally, grinding and shimming are used at the next assembly operation to produce an acceptable mating surface.

NAD uses concurrent curing to solve this problem. Concurrent curing is similar to co-curing of assemblies in that all parts are cured together within the same tool at the same time. But in concurrent curing, a Teflon slip sheet is placed between the mating part surfaces to prevent resin flow through these surfaces. After the cure cycle has been completed, the assembly is removed from the curing tool and disassembled, with the Teflon slip sheets discarded. Honeycomb core can be added at this time, along with other required parts. The cured composite parts are reassembled with exact mating surfaces and are bonded or fastened to complete the assembly.

This process results in a better fit for part assemblies and eliminates gap measurement and shimming. Assembly labor is also reduced.

SUBCONTRACTOR MANAGEMENT

Effective subcontractor control is a strategic objective given top management priority at NAD. The company uses a three-phase approach, based on the guidelines of the Subcontractor Control Template, carefully structured to avoid the four traps identified in NAVSO P-6071.

Phase I is planning. Members of the Subcontract Management Team (SMT) are assigned from key functional disciplines, such as subcontract administration, program management, engineering, manufacturing, and quality. During the planning process the team is responsible for defining requirements and establishing source selection and performance measurement criteria.

Phase II is the source selection process. The optimal supplier is determined based on evaluation of the following criterion categories: technical approach, organization and management capability, schedule, quality control, price, product support and logistics, and special considerations. The percentage weight given to each criterion category was determined and assigned during phase I planning but not made known to the bidders. The SMT surveys all potential suppliers. Experts from the functional disciplines assist the SMT in evaluating the proposals.

Phase III is subcontract management. The SMT measures and monitors progress and conformance. Control devices include in-process reviews, design reviews, quality audits, and regional offices. Progress payments are used to motivate and verify performance.

The NAD subcontractor management approach promotes communication and coordination with suppliers. It facilitates objective selection of the best supplier offering at lowest "evaluated" cost. The program is very successful. Savings attributed to enhanced subcontractor management during 1987 - 1988 include: inventory reduced by 26%, cost of late deliveries reduced by 29%, cost of nonconformances reduced by 15%, and late requisitions reduced by 45%.

SUPPLIER PERFORMANCE RATING SYSTEM

In 1984, NAD decided that its ability to compete was being threatened. Over 50% of supplier deliveries had paperwork or hardware nonconformances or did not meet the delivery schedule. The added administrative cost of these deficiencies was estimated at $5 to $10 million per year.

The Division realized that a hands-on relationship with its suppliers must be established. As a result, the Supplier Performance Rating System (SPRS) was established. The system's objectives include:

* Identifying and assigning the responsibility for quality and schedule problems.
* Motivating suppliers to improve quality and delivery performance.
* Meeting the customer's requirements.

SPRS measures and rates suppliers on quality and schedule criteria and also on the added cost of poor quality and delivery. It is also used to help determine which suppliers qualify for NAD's Key Plan (incoming lots of material from a Key Plan supplier are audited by sampling rather than by 100% inspection), which suppliers need help in meeting schedule and quality standards, and finally, which suppliers give the best value for the material dollars spent.

SPRS is a computer-based system that is linked to an Automated Material System, which is the source of delivery data, and to the Supplier Quality Rating System (SQRS), which is the source of quality inspection data. In 1989, SPRS reports on quality, schedule, and added cost will be sent out quarterly to more than 500 suppliers. The Division's goal is to form a team with each supplier. The SQRS reports will serve to open another communications channel between the team members.

SUPPLIER TECHNICAL ASSISTANCE AND REPORTING STATUS SYSTEM

The Supplier Technical Assistance and Reporting Status (STARS) system is being implemented to make maximum use of electronic data interchange (EDI) for the paperless processing of business transactions. The system will provide closed loop feedback between NAD and its principal subcontractors and major suppliers.

For principal subcontractors, the system architecture will support secured communications on a direct line, video conferencing, and the transfer of data. For major suppliers, STARS will use a third party commercial communications network, which is secured by a data protection package. The network will support the transfer of purchase orders, supplier status feedback, delinquency reports, process specifications, and change notifications.

The pilot phase of STARS has been successfully tested with five major suppliers. The immediate goal is to convert from a pilot status to production. Subsequent goals address subcontractor status reporting, electronic mail integration, and process specification via text and graphics transfer.

FABRICATION OF TOOLING FROM THREE-DIMENSIONAL SURFACE DATA

NAD is using 3-D surface loft data to fabricate composite tooling for precision airstream moldline surfaces. The 3-D surface data is used to produce DNC machined bulk graphite tool segments, which are assembled together to form the part moldline. Composite plies are then laid up on the graphite tool and cured to produce the tool face. This tool face is then attached to the supporting box, which is made of composite laminates, to form the production tool.

Fabrication of tooling in this manner creates a master tool model based on 3-D part data rather than on hand built plaster splashes. Surface data is consistent throughout fabrication, subassembly, and assembly and can be readily verified by referencing the original 3-D part data. Ease of machining allows for shorter tool lead times and for flexibility in reacting to skin detail design changes.

TOOLING COMPUTER AIDED DESIGN/TOOLING COMPUTER AIDED MANUFACTURING

Tooling Computer Aided Design/Tooling Computer Aided Manufacturing (TCAD/TCAM) are component programs of the NAD computer graphics systems. They are used to aid in the design and manufacture of production tooling. The notable feature of this system is that the NCAD 3-D database is used as the source of part geometry. This ensures both part accuracy and a high degree of configuration control. Another benefit of this approach is the standardization of tool manufacturing practices.

TCAD/TCAM have been used for headerboard and master model generation on the ATF program, resulting in significant time and labor savings. For example, a 160" x 220" headerboard assembly was designed, fabricated, and inspected in eight weeks without the use of overtime. If conventional processes had been used, this assembly would have taken 16 weeks with the use of overtime.

Another tool produced by this automated method is the acrylic scribe template, which is used in the fabrication of sheet metal parts. Tool geometric data is passed to a Laserdyne 28" x 42" laser, which both cuts out and etches the tool. This tool is disposed of at the end of each production lot, which improves configuration control. The laser cut edge has a distinctive finish and will easily show evidence of excess wear or tampering. This leads to improved quality.

DECOUPLING OF COMPOSITE LAY-UP FROM CURE TOOLING

During the composite fabrication process, typically one tool or mold is used for both the lay-up and curing stages. NAD has developed a technique that uses two sets of tools to improve the overall process.

The two sets of tooling decouple the lay-up from the curing stage. Less precision is required during the lay-up stage so an 80% less costly tool may be used. Furthermore, during the lay-up process, convex tooling is preferred because it typically simplifies positioning problems for lay-up personnel. The use of cutting knives during this stage also tends to result in more wear and tear on the tool. NAD uses more, but less-costly lay-up tools to allow lay-up workers to proceed independently of autoclave queues. Wear and tear on the lay-up tool does not affect the lay-up process.

Due to the batch nature of the curing process, hundreds of parts may be cured at the same time. Essentially all of the tools become available for reloading at the same time. The decoupled two-stage tooling improves turnaround by reducing the set-up time for these more precise tools. The total number of tools with tight tolerance is reduced, improving repeatability and accuracy. Since most of the wear and tear on the tool occurs during the lay-up stage, the life of the more expensive curing tool is prolonged.

NAD has implemented this practice on selected F/A-18, N-14, and YF-23 composite parts. It is expected that this technique will be applicable to frames, longerons, ribs, spars, and smaller skins on the F-23. Due to lay-up transfer difficulty, the process cannot be used on very large skins. A few of the benefits that have been identified as a result of the application of this technique include:

* More uniform center work load.
* Reduced quantities of more expensive cure tooling.
* Better assembly accuracy and repeatability through the use of fewer cure tools.
* Better lay-up tooling productivity aids.
* Reduced wear and tear on the more expensive cure tooling.
* Enhanced surge and recovery capacity.

NAD estimates that through the use of decoupled tooling, it has reduced the average turnaround cycle for a tool from three days to one day. Under surge conditions, NAD estimates that this turnaround time could be reduced to about nine hours; i.e., one hour set-up and eight hours autoclave time.

EXPERT PROCESS PLANNING SYSTEM

NAD has developed an expert generative planning system for aluminum sheetmetal and extrusion parts. Although the Expert System Planner (ESP) is not yet in full production use, it has been validated on 46 typical parts. The 46 parts represent a cross section of the types of parts that Fabrication Planning encounters. More than 90% of the plans generated by the system are 100% correct. The time to generate a plan has been reduced from between two to three hours to less than 30 minutes.

To generate a new plan, a user first answers a series of questions about the description of the part. The part describing information is obtained from the engineering drawing or the engineering parts list. This front-end to the system was developed and implemented using the Decision Classification System (DCLASS) developed by Brigham Young University. From this dialogue, the system generates a structured data file, which describes the part in terms of key attributes.

The DCLASS part data file is transferred over the LAN to a file server, where it is queued for processing. A LISP machine continously polls the file server for data files, and will extract a file when present. The data from the file is then inserted into ESP and the processing begins. ESP is a rule based expert system that is built in a frame based expert system shell known as Knowledge Engineering Environment (KEE) developed by Intellicorp. The process plan is created after the rules are traversed and LISP functions are executed.

ESP currently resides on two different hardware platforms. The old platform consists of IBM PC's (DCLASS front-end), Xerox 8000 file server, and a Xerox 1186 LISP machine (KEE). The Xerox 1186 runs KEE in an Interlisp-D environment. ESP will migrate to a newer Unix based platform, which consists of Hewlett Packard and SUN workstations, along with IBM PC's and MAC II workstations. ESP resides on a SUN 3/160 workstation, which runs KEE in a common Lisp environment. The DCLASS front-end can run on any of the workstations.

Four major benefits that are expected from the ESP system include:

* Expert knowledge will be maintained in the system rather than within the minds of employees who may leave the company.
* Generation time for plans will decrease.
* Plans will follow a consistent philosophy.
* Fewer errors will occur in plans that are generated automatically.

The system is currently being readied for production use, including the replanning of 6,000 to 7,000 parts.

MANUFACTURING SIMULATION

NAD is performing discrete, event simulation of manufacturing scenarios using an extended version of the SIMKIT simulation software from Intellicorp. The software runs in a LISP environment on Symbolics hardware.

The NAD simulations seem somewhat unique in their ability to handle very complex manufacturing scenarios with what appears to be very high fidelity and acceptable speed. The simulations include spreadsheets of manufacturing scenarios, bottleneck detection, testing of automated scheduling programs, and display of data in a variety of modes, including graphical in-motion models.

Simulations have already been performed to help optimize a number of production areas, including the Small Parts Sheetmetal cell and a McDonnell Douglas automated guided vehicle requirement in St. Louis, Missouri.

MULTI-AXIS COMPUTER AIDED MANUFACTURING

In the past, NAD, along with other manufacturers, has been dependent on a manual method of producing the Automatic Program Tool (APT) code for their NC machines. The APT language was developed in the 1950's and requires a very highly skilled programmer with many hours of machine shop experience.

NAD's solution to this labor intensive problem is Multi-Axis Computer Aided Manufacturing (MAXCAM). This system was developed to utilize the computer graphics data available in the NCAD system and nearly automatically generates three to five axis machine code. MAXCAM uses a series of menu screens to allow the programmer to establish part staging. The MAXCAM system can produce the NC code three to eight times faster then the APT programming language process.

NAD has also developed a computerized Part Verification System (PVS). The MAXCAM NC program code is used by PVS to prove the process prior to the machining of the first part. PVS produces a model of the part on a color graphics display terminal and allows the user to view the cutter path motion as it would occur during the actual machining process. PVS has reduced the number of part program try-outs at the NC machine level by 85%.

The MAXCAM and PVS systems have provided NAD with an extremely efficient method of developing and proving out the program code for most of the NC machines that are in use today.

COORDINATE MEASURING MACHINES

NAD has developed the ability to utilize the new Dimensional Measurement Interface Specification (DMIS) as a means to control its coordinate measuring machines (CMM's) via the CAD database. Seed funding for the program was provided by the Industrial Modernization Incentives Program (IMIP).

The NC facility of NCAD is utilized to create a general point-to-point NC file. This file is then transparently laundered through DMIS to any of the CMM post-processors. Following this, the post-processed file is downloaded to the specific CMM.

For the IMIP, the target CMM is a new British-made LK Metre Four Microvector dual horizontal arm CMM. The machine uses a flexible, two axes wrist and an automatic probe change, plus contact and non-contact (laser) probes. The LK is a totally air-supported machine with granite columns and a four-foot granite base. It can either inspect both sides of a single three-foot square part or single sides of two such parts. Of great benefit to NAD was the extreme degree of care that went into development of the machine's acceptance criteria.

The host computer system is an HP-1000 Model 29 with an A900 series processor. The NAD 3-D graphics system, Wise Product Definition (WPD), is used to generate complete part programs at a graphics terminal, greatly reducing part programming and proving time. Part programs are post processed to the DMIS format and downloaded to the CMM. DMIS provides a standard interface for exchange of inspection data between remote computer systems and the CMM. It also provides a common format for analysis and storage of all data at all system levels from CMM to the host to CAD system.

Additional peripheral support for the CMM includes three terminals (one for each of two possible simultaneous parts and one for system and downloading chores) and a plotter. The plotter is utilized for verifying inspection points when a non-contact laser probe is used in place of a ruby-tipped contact probe.

3.4 FACILITIES

MANUFACTURING INITIATIVES PROCESS

NAD has implemented a formalized process to systematically evaluate and prioritize factory modernization projects which support a manufacturing strategy designed to transition from the current "as is" to the future "to be" environment. The system is called the Manufacturing Initiatives Process (MIP). It includes phased authorization with review and approval at key points in the project development cycle based on increasing levels of detail. Project evaluation criteria also include ROI calculated by using a Cost Definition (CDEF) model.

The MIP supports the Manufacturing Initiatives Plan which has been developed to provide time-phased quantifiable goals for the manufacturing portion of the NADSAP. Projects are developed from a variety of sources including center teams that have been formed in the various manufacturing functional areas. Each candidate project must fit into the overall NADSARP framework and is subjected to periodic review by the Project Assessment and Authorization System (PAAS). The PAAS review is conducted by a four member PAAS committee composed of senior level managers from the various functional areas. The review process requires total concensus for project continuation.

Future plans include implementation of a mainframe based ARTEMIS network system to allow development and review of critical path data for all projects.

THEODOLITE SYSTEMS

NAD has upgraded its theodolite non-contact measurement capability from a WILDCAT 2000 system to a TOMCAT 2000 system. This upgrade provides a multi-head capability that can run up to six theodolite instruments at one time, as opposed to only two under the old system. The multi-head capability increases accuracy and versatility. The machine can be set to shoot multiple surfaces on the same subject. The system facilitates rapid and accurate measurement of jigs and fixtures as well as production assemblies.

The TOMCAT system runs on an HP 9000 CPU with six data communication board positions, a 20 MB hard drive, and a 3.5" floppy disk. NAD is currently testing the new MANCAT system using an HP Vectra 386-16 MH2 computer, which is compatible with the IBM AT, and a modular software design using Microsoft Pascal that will allow 14 stations, with eight on-line at the same time.

NAD has demonstrated gageless tooling measurement and plans to develop a direct link for data transfer from and to the mainframe based 3-D graphics model. Benefits include:

* Reduced error propagation by providing angular redundancy on point generation through the use of multiple head software.
* Reduced rework savings of 57% of hours allotted to 11 tool orders that were randomly picked to be reworked by theodolite.
* Reduced theodolite system downtime for repositioning instruments due to visibility restrictions by 90%.

TUBE BENDING

NAD is using a self-correcting CAD to CAM system called T-Bend for aircraft tubing. Much of the experienced tube bender's art has been replaced by the new system.

The data for each tube is generated in cartesian coordinate format from a 3-D CAD database (McDonnell Douglas Automation's Computer Aided Design and Drafting system). These coordinates are periodically downloaded to shop floor microcomputers. Master data remains on the mainframe, and the shop floor version is constantly checked to ensure that it mirrors the master.

Data is then post-processed to produce the specific form of polar coordinates required by tube inspection and bending machines. Tube fabrication software compensates for spring-back and other factors to provide a first tube. This tube is placed on an inspection machine, which subsequently generates a delta file (the difference between design data and the actual tube configuration). Significant errors are used as compensation to the post-processed file, and the cycle is repeated, if necessary, until acceptable tubes are produced. In reality, the program is sophisticated enough so that the first tube is almost always within tolerance.

The operation represents a significant manufacturing improvement. Some of the key benefits are:

* Elimination of master tube storage and damage.
* Reduction in operator training requirements.
* An 80% reduction in flow-time.
* Improved process control.
* Reduction in scrap.

NON-FILM RADIOGRAPHY OF COMPOSITE PARTS

NAD has developed and implemented into production a non-film radiography cell, which reduces radiographic inspection costs of composite parts while retaining sensitivity and specification requirements. The objectives of the program were to reduce set-up time, eliminate film use, provide better data evaluation and storage and retrieval, and reduce new tooling costs.

Existing part tooling was modified with a part positioner/yoke combination to enable rotation of the part within the x-ray cell. A Cybotech G-80 electric gantry robot is used to manipulate a "C" fixture, which holds the x-ray source and Synergistic x-ray imager, along the part following a programmed sequence. The real-time images of the part are downloaded to the host computer for later evaluation by a radiographer. The system offers image intensifying to exaggerate density variations, to sharpen image quality and to magnify the image.

Currently, the system uses teach programming and a 480 x 380 pixel screen. Enhancements to the system would provide off-line programming and a 1,000 x 1,000 pixel screen for greater resolution. Also, using Giga tape for data image storage rather than magnetic tape would allow one tape cassette to replace 57 magnetic tapes.

Presently, the F/A-18 rudder has been approved for non-film inspection. Validation of more F/A-18 parts, such as access covers, leading edge assemblies, landing gear doors, and speed brakes, is in process. With the non-film radiography cell, manual manipulation of the part has been significantly reduced, and the need for film and copy storage has been completely eliminated. Additionally, the cell eliminates the danger of x-ray exposure by removing the need for an inspector to continuously enter the x-ray room.

SMALL PARTS SHEET METAL WORK CELL

NAD has implemented a small parts sheet metal work cell for the fabrication of small aluminum sheet and extruded parts for the F/A-18 program. The objectives of the small parts cell were to reduce labor costs, flow time, and WIP by combining group and cell technologies into a single work cell and consolidating all fabrication operations for these small parts families. The families consist of parts that are less than 20" in any direction and do not require heat treating operations.

Daily part orders are downloaded to the cell from an IBM Series I cell computer. Based on the part orders, raw materials and tools are retrieved from on-site storage systems through a direct link to the cell controller. An automated material handling conveyor system carries materials and tools throughout the cell in stainless steel baskets. Reflecting tabs are located on the side of the baskets and are adjusted to indicate the next station. Optical scanners throughout the conveyor system note the tab location and route the basket accordingly.

The cell contains brake presses, cut-off saws, a three-spindle profiler, punch press, deburring station, and the metal finishing process station. (Due to environmental restrictions, this last station is currently not on-line.) Real-time status of the cell is identified through the use of a shop floor computer control system.

The small parts sheet metal work cell has reduced average cycle time from eight to ten weeks down to five to seven days. It has provided a large indirect labor savings due to the elimination of redundant and unnecessary transportation of orders and due to a real-time tracking system, which eliminates the time spent locating material, parts, and tools. WIP has been reduced and part quality and production readiness have been improved.

Figure 3.4-1: Small Parts Sheetmetal Work Cell

FLEXIBLE TURNING CELL

NAD is currently in the process of completing implementation of a flexible turning cell for the F/A-18 fuel fittings and other turned parts.

Turning, milling, drilling, and deburring operations were previously performed in widely separated functional departments. Manual part loading and unloading were peformed by skilled labor. The NC programs were generated by a programming system which was not optimal for the work being performed. Support labor performed all scheduling, expediting, and material handling tasks.

The flexible turning cell consists of four Okuma LC20-M C-axis lathes capable of both turning and milling operations. Two of the lathes are equipped with Okuma OR20 pick and place robots, and the other two lathes are equipped with LNS Superhydrobar feeders able to handle stock ranging in diameter from 1/2" up to 2-3/4". While inside the bar feeder, the stock is supported using hydrodynamic oil. The machine's CNC graphics capability allows the part, tool, and tool motion to be displayed in real time as cutting occurs, or simulated prior to cutting.

Figure 3.4-2: Flexible Turning Cell

The flexible turning cell uses a new graphic programming system supplied by CIMLINC, Incorporated, which generates the machine's NC programs. The programming system automatically generates a graphics and text machine operator's instruction document, which describes how to set up the machine and how the NC program will cut the part. The cell control system uses an Ethernet LAN and performs DNC, machine tool monitoring, scheduling, and reporting functions. The latest production order information is downloaded each night and schedules are automatically generated for the next day's work.

Preset modular cutting tools are used to reduce set-up time. In presetting, tool offsets are measured and recorded. When the tools are loaded into the lathe, offset information is downloaded and the part program is adjusted.

Implementation of the cell is largely complete with all major equipment and systems implemented. Full production is scheduled to begin in October 1989.

3.5 LOGISTICS

PRODUCT SUPPORT CENTER

NAD has several approaches for focusing on an integrated contractor database that meets ATF and CALS objectives. The database consists of product definition, product delivery, and product support centers. The product support center, the focus of this discussion, is responsible for the supportability of the product. The product, as defined, is maintained and enhanced by the support center, which also develops its own product line of technical services, training, training systems, service modifications, repairs, interim contractor support, warranty tracking, site activation services, spares, and provisioning data.

Early in the product definition cycle, the product support center ensures that the weapon system will be supportable when it is fielded. The ATF design team concept includes a logistics engineer, whose goals are to increase the design engineer's understanding of the operational environment and to increase the designer's involvement in the reliability, maintainability, and supportability process.

To support this involvement, several automated modules are implemented in the ATF product support center.

* The Product Assurance Workstation (PAWS) is a designer's aid for the development of failure modes, repair tasks, and test parameter diagnostics. PAWS is a tool that cultivates the designer's inate desire to incorporate robust characteristics and a maintainable configuration before the design is frozen. PAWS uses the resources of the common engineering database.

* The Supportability Design Influence/Supportability Design Data System (SDI/SDDS) module provides the mechanism to document the analysis leading to supportability considerations. SDI/SDDS documents the results of analysis by using MIL-STD-1388-1A 200 series tasks. It exploits the use of existing DOD weapons systems data for establishing new equipment design goals and technologies. This module produces supportability design criteria for new weapons systems and equipment.

* The Logistics Support Management Information System (LSMIS) stores, manages, and integrates the development of all major logistics data concerning the Logistics Support Analysis (LSA) process. LSA triggers further definition of the support equipment training, technical data, supply support, and facilities requirements. The system provides subcontractor integration and customer visibility for review and approval of support resources via secured datalink. Also featured in LSMIS is the capability to adjudicate failure reporting analysis and corrective actions (FRACAS). The on-line system provides review at the customer's remote terminal, "dispute" capability at the customer's terminal, comments to the Joint Reliability Maintainability Evaluation Team (JRMET) and answers to the customer's questions.

ADVANCED TRAINING SYSTEMS DEVELOPMENT

Historically, training systems have lagged the systems that they support by several years. This is true for both the initial design and subsequent design changes. When finally delivered, the training systems do not always fulfill the training requirements.

As part of the ATF competiton, NAD is designing both the pilot and maintenance training systems concurrently with the actual airframe design. It is stressing commonality of hardware among the various levels of simulators and training tools. A database has been developed to provide traceability of requirements, to track results, and to better select training media.

IMPROVED TECHNICAL DATA SYSTEM

The Improved Technical Data System (ITDS) is an on-line system developed by NAD to improve the availability and accuracy of technical data to maintenance personnel. Each user system consists of a local library with an expandable two gigabyte memory networked to devices in the shop, such as microcomputer terminals with high resolution color graphics displays, printers, and automatic test equipment. A portable battery operated delivery device can be used to carry data directly to the aircraft for maintenance actions. Data may be uploaded and downloaded between the local library and the portable device.

ITDS allows direct use of engineering drawings. It greatly improves data accuracy and configuration control of technical data. Technical data can be retrieved and updated rapidly. It interfaces with the maintenance data and supply systems. The system conforms to all current military standards including CALS.

3.6 MANAGEMENT

NORTHROP AIRCRAFT DIVISION STRATEGIC ARCHITECTURE PLAN

NAD originally developed the Northrop Aircraft Division Strategic Architecture Plan (NADSARP) to be a strategic plan for data processing systems. It soon became apparent that significant improvements in cost and schedule would not be achieved by a data oriented architecture, but by a process and user oriented one. The architecture should drive data processing, satisfy the implications mandated by the Department of Defense CALS initiative, and drive other types of 1990 - 1995 projects as well.

Past practice dictated decisions on development and improvement projects based solely on a potential return on investment (ROI). These projects were developed by functional organizations. In some cases, data processing applications that were needed to bridge the gap between these functional organizations were not approved because they did not have an acceptable ROI.

The NADSARP spans five major process centers: product definition and development, central requirements, manufacturing, material acquisiton, and product support. All centers share a common data base. The core of the architecture is the central requirements center which is now being structured around a Manufacturing Resource Planning (MRP) II system.

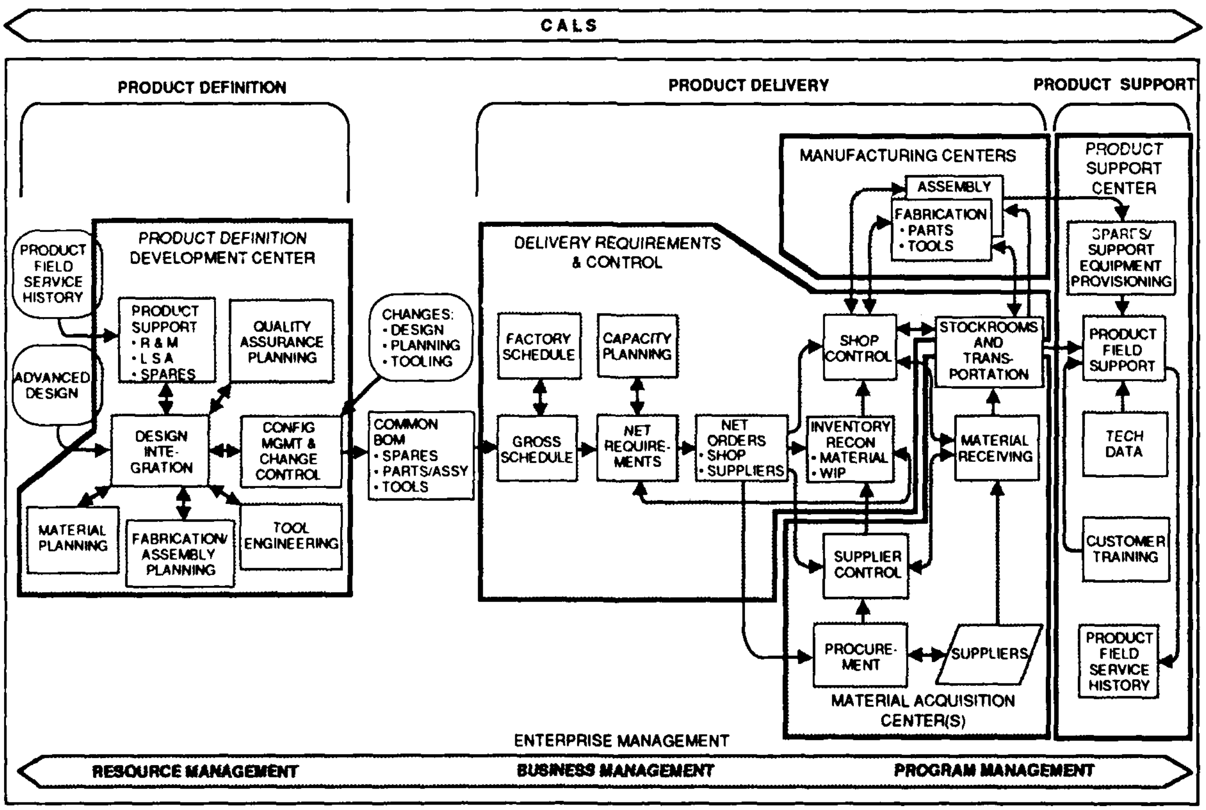

Figure 3.6-1: NADSARP Functional Architecture

Since the completion of the NADSARP planning document, only those projects fitting the architecture are approved. ROI considerations are of secondary importance. Resources are being diverted from non-NADSARP projects. The architecture provides a framework for all functional activities in the NAD.

Although the NADSARP architecture was complet^d in 1986, work continues to keep it updated. Recent steps are incorporating business functions such as finance, contracts, and pricing. Upgrades for integrated logistics support, program management, services and resources, and CALS are also underway.

INSTITUTIONALIZING THE DOD 4245.7-M TEMPLATES AT NAD

NAD has initiated a program to institutionalize the DOD 4245.7-M templates. It is based on a system that requires quarterly review of each designated program at the corporate vice president level. Under the new system, each program manager is required to assess and report compliance with the templates. The program will be fully implemented by the end of 1989. This initiative will provide significant advantages to NAD as more DOD acquisition programs begin requiring template formats for program reviews. Besides actively working to implement the DOD 4245.7-M templates at NAD, the company reviewed DOD 4245.7-M and compared it to NADSARP. The results were enlightening and led to recommendations for improving the templates and NADSARP and to add coverage to important areas not addressed by either.

The study found NADSARP to be, more enterprising and process oriented as compared to the DOD templates, which take more of a program view and are more product oriented. NADSARP provides a good top-down framework for understanding the principles and risk reduction measures defined in the DOD templates. Because of this compatibility, most of the templates can be mapped directly into the NADSARP architecture. NAD views the templates as focusing primarily on two critical contractor team processes: concurrent engineering, which is defined in NADSARP as the "Product Definition" process, and subcontract management, which is being developed by NAD as the NADSARP "Material Acquisition" process.

A major conclusion of the NAD comparison was that neither NADSARP nor the DOD templates identified the overall cost management process, which NAD believes should be a joint customer-contractor team process focusing on process cost rather than product cost. NAD also recommended developing a non-process oriented view of customer-contractor team interactions driven by DOD approved long-range goals, such as reduced program cost and schedule, reduced product life cycle cost, improved product availability, and improved customer-contractor shared information.

MANUFACTURING ENGINEER ASSOCIATES PROGRAM

The NAD Manufacturing Engineer Associates (MEA) program is a two-year rotational training program designed for recent engineering graduates to develop into well-rounded manufacturing engineers.

Manufacturing engineers are recruited to NAD primarily from a select group of schools offering four year manufacturing engineering or related degrees. Each MEA is rotated through assignments in 12 to 14 fabrication and assembly departments. They receive hands-on experience while learning how the various departments operate and relate to each other. The training program is tailored to the needs and talents of each participant. The basic program is as follows:

*	Planning (fabrication and assembly)	20 weeks
*	Liaison (fabrication and assembly)	20 weeks
*	Tool Design (fabrication and assembly) (includes 40 hours CADAM and 40 hours NCAD instruction)	20 weeks
*	Tool Engineering (fabrication and assembly)	20 weeks
*	Numerical Control Programming	8 weeks
*	Master Dimensions (includes 40 hours NCAL instruction)	2 weeks
*	New Program Development	2 weeks
*	Graphite Composites Liaison/Tool Engineering or Manufacturing Technology	8 weeks
*	Offsite Liaison/Tool Engineering	8 weeks
*	Fabrication or Assembly Production Development Manufacturing Technology	8 weeks
*	Tooling Manufacturing Graphics Center	8 weeks
*	Composites Processing Automation	8 weeks

Since 1970, 120 engineers have completed the training program. Graduates have established an excellent reputation as highly skilled, technically competent, well-rounded manufacturing engineers. Most have advanced rapidly. The program benefits the company by providing a source of highly skilled manufacturing engineers to work on key projects.

IMPLEMENTATION OF MANUFACTURING RESOURCE PLANNING PROGRAM

NAD is implementing Manufacturing Resource Planning (MRP) II as a part of the long range NADSARP architecture. The Division is following the path established by the B2 Division, which completed its implementation in October 1987. The first phase of implementation is imminent. This discussion does not deal with the technical aspect of the MRP II itself, but with the cultural changes, training, testing, user acceptance, and software documentation required for a successful implementation across the entire Division.

The MRP II implementation process has prompted an analysis of what cultural features should be retained, discarded, added, and restructured. Organizations will have to expand their knowledge in order to understand the jobs that precede theirs as well as those jobs that will follow. A functional MRP II user cannot stand alone. He will be part of a larger and, by necessity, more accurate system for controlling manufacturing resources. Other cultural changes being motivated by the adoption of MRP II will affect program directors, project teams, team building activities, the change board process, user training curricula, training materials, management involvement, and human resources support teams.

Training the managers and the general workforce in MRP II principles will be a continuing effort even after implementation. Of a current labor force of 20,000 people, more than 3,000 have now received MRP II training. Most of the training was given by line managers who were trained by the MRP Implementation Team. In all, 38 courses were developed. The classroom sessions varied in duration from 1-1/2 to 8 hours. In addition, on-the-job training programs and after duty hours accredited courses were offered and eagerly accepted by the employees. The MRP II Training Resources Catalog was prepared to describe all courses according to purpose, audience, schedule, location, and prerequisites.

The first phase of MRP II will be implemented at the conclusion of a series of performance tests using the architecture. The testing approach involved three phases: module acceptance tests, preproduction tests, and user acceptance tests. Well defined procedures were established for dealing with issues that were not accommodated by the architecture, for applying critical fixes and for documenting all software configuration modifications. The current schedule provides for all phases of the project to be complete in mid-1990.

3.7 TOTAL QUALITY MANAGEMENT

TOTAL QUALITY MANAGEMENT

NAD has taken an aggressive and comprehensive approach to implementing continuous process improvement through Total Quality Management (TQM). The goal is increased competitiveness through improved product quality and cost-effective processes. A secondary goal is the improved employee satisfaction derived from involvement in the improvement efforts and the reduction in bureaucracy.

The program has top level management support and commitment. All organizations and programs at NAD are involved and have responsibilities under the program. The TQM philosophy is built on the NADSARP structure and incorporates all existing quality improvement activities such as MRP II, productivity improvement programs, employee performance recognition, expert systems, and others.

The TQM program is directed by a full-time program manager, who reports directly to the General Manager and is guided by a corporate TQM Steering Committee. A comprehensive implementation plan has been developed and approved. Extensive training of top level executives has been completed.

Future activities involve education and training of all employees, supplier involvement, and program assessment. The department facilitators are the key members of department teams. They are responsible for developing a department mission statement and identifying processes for improvement. Full time department facilitators are being selected and trained. Facilitators will be selected from a pool of high potential, motivated individuals. They will be assigned to this position for one to two years.

The NAD TQM plan also calls for the formation of Critical Process Review teams responsible for multi-functional process improvement. These teams map out the process, identify root causes of problems, select solutions, and oversee implementation. The plan identifies an initial list of targeted processes for 1989.

SECTION 4

PROBLEM AREAS

4.1 MANAGEMENT

IDENTIFICATION OF PROJECT COST SAVINGS

Current cost benefits analysis methods are based only on direct cost savings. A burden factor is applied to estimate the indirect cost savings, manufacturing overhead, and general and administrative overhead to result in total project savings. New materials and processes, increased emphasis on "above the shop floor" functions, and interrelated improvements are leaving direct labor activities as being only 10% of product cost. Current cost benefits methods are not designed to account for the remaining 90%, thereby grossly distorting real cost savings analysis.

NAD is experimenting with a Cost Definition (CDEF) approach to identifying cost savings. CDEF is a discrete method of identifying both direct and indirect cost savings by assigning all costs to Integrated Computer Aided Manufacturing Definition (IDEF) activity models.

An IDEF analysis continuously breaks down all functions into smaller and smaller nodes, creating a node tree. The amount of time spent by each cost center on each node is determined through interviews with budget or cost center personnel. Although these are only estimates, they are done at such a small discrete level that the aggregate estimates are generally accurate. Organization costs are assigned to functions, resulting in a total cost by function and a cost by element.

NAD's cost profile is changing to include new business bases, new processes and methods, and new materials. Its baseline accounting must be extended to determine the time period of analysis; to define future assumptions such as business base, escalation factors, and technology improvements; and to classify cost behavior.

Using CDEF, the result is a total model, which shows how each functional area fits into the overall strategy. With a system such as this, a manager working on multiple programs can determine how a process change will affect the entire business base. CDEF more accurately identifies real savings resulting from technology improvements and improves the strategic planning process.

NAD is currently exploring the means to obtain DOD approval to use CDEF methodology when issuing new proposals and the means to transition from current practices to CDEF.

APPENDIX A

TABLE OF ACRONYMS

Acronym	Definition
2-D	Two-Dimensional
3-D	Three-Dimensional
AFFTIS	Air Force Flight Test Instrumentation System
AFPRO	Air Force Plant Representative Office
AMRF	Automated Manufacturing Research Facility
APT	Automatic Program Tool
ARINC	Aeronautical Radio, Inc.
ASTROS	Automated Structural Optimization System
ATF	Advanced Tactical Fighter
BMP	Best Manufacturing Practices
CAD	Computer Aided Design
CALS	Computer Aided Acquisition and Logistics Support
CDEF	Cost Definition
CINDA	Chrysler Improved Numerical Differencing Analyzer
CMM	Coordinate Measuring Machine
DCLASS	Decision Classification System
DMIS	Dimensional Measurement Interface Specification
DNC	Direct Numerical Control
DOD	Department of Defense
DOD-STD	Department of Defense Standard
DPM	Digital Product Model
EDI	Electronic Data Interchange
EMPF	Electronics Manufacturing Productivity Facility
ESP	Expert System Planner
FRACAS	Failure Reporting and Corrective Actions
FSD	Full Scale Development
ICMS	Integrated Configuration Management System
IDEF	Integrated Computer Aided Manufacturing Definition
IMIP	Industrial Modernization Incentives Program
IMPCA	Integrated Planning and Control for Assembly
ISSL	Integrated Systems Simulation Laboratory
ITDS	Improved Technical Data System
JRMET	Joint Reliability Maintainability Evaluation Team
LISP	List Processing
LSA	Logistics Support Analysis
LSMIS	Logistics Support Management Information System

MAXCAM	Multi-Axis Computer Aided Manufacturing
MEA	Manufacturing Engineer Associates
MIL-STD	Military Standard
MIP	Manufacturing Initiatives Process
MRP	Manufacturing Resource Planning
MTI	Metalworking Technology, Inc.
NAD	Northrop Aircraft Division
NADSARP	Northrop Aircraft Division Strategic Architecture Plan
NC	Numerically Controlled
NCAD	Northrop Computer Aided Design
NCASA	Northrop Computer Aided Structural Analysis
NORLOADS	Northrop Integrated Maneuver Loads Analysis Procedure
PAAS	Project Assessment and Authorization System
PAWS	Product Assurance Workstation
PDBS	Product Definition Business System
PDDC	Product Definition Development Center
PDES	Product Data Exchange Specification
PPPS	Proven Production Process Specification
PPRS	Phased Parallel Release System
PVS	Part Verification System
RAMCOMP	Rapid Multi-Disciplinary Computational Methods Program
RCS	Radar Cross Section
ROI	Return On Investment
SDI/SDDS	Supportability Design Influence/Supportability Design Data System
SIMKIT	Simulation Kit
SMT	Subcontractor Management Team
SPRS	Supplier Performance Rating System
SQRS	Supplier Quality Rating System
STARS	Supplier Technical Assistance and Reporting Status
TCAD/TCAM	Tooling Computer Aided Design/Tooling Computer Aided Manufacturing
TQM	Total Quality Management
WIP	Work-in-Process
WPD	Wise Product Definition

APPENDIX B

BMP REVIEW TEAM

Team Member	Agency	Role
Leo Plonsky (215) 897-6686	**Naval Industrial Resources Support Activity** Philadelphia, PA	**Team Chairman**
Ed Turissini (317) 351-4200	**Naval Avionics Center** Indianapolis, IN	**Team Leader** Design & Test
Ernest Screen (301) 227-1350	**David Taylor Research Center** Bethesda, MD	
Thomas Crosby (301) 863-1660	**Naval Air Test Center** Patuxent River, MD	
Ted Brindle (317) 353-7921	**Naval Avionics Center** Indianapolis, IN	
Robert Jenkins (202) 227-1363	**David Taylor Research Center** Bethesda, MD	**Team Leader** Prod & Facilities
Richard Celin (201) 323-2173	**Naval Air Engineering Center** Lakehurst, NJ	
Charles McLean (301) 975-3511	**National Institute of Standards and Technology** Gaithersburg, MD	
CDR Mark Cooper (805) 756-2571	**Naval Sea Systems Command** San Luis Obispo, CA	
CDR Richard Purcell (202) 692-3422	**Office of the Assistant Secretary of the Navy (S&L) (RM&QA-PI)** Washington, DC	**Team Leader** Mgmt & Logistics
Gaylen Fischer (309) 782-6718	**U.S. Army Industrial Engineering Activity** Rock Island, IL	

APPENDIX C

PREVIOUSLY COMPLETED SURVEYS

BMP surveys have been conducted at the companies listed below. Copies of survey reports for any of these companies may be obtained by contacting:

Best Manufacturing Practices Program
Office of the Assistant Secretary of the Navy
(Shipbuilding and Logistics)
Attn: Mr. Ernie Renner, RM&QA
Washington, DC 20360-5000
Telephone: (202) 692-0121

COMPANIES SURVEYED

Litton Systems, Inc.
Guidance & Control Systems Div.
Woodland Hills, CA
October 1985

Honeywell, Inc.
Underseas Systems Division
Hopkins, MN
January 1986

Texas Instruments
Defense Sys & Electronics Group
Lewisville, TX
May 1986

General Dynamics
Pomona Division
Pomona, CA
August 1986

Harris Corporation
Government Support Systems Div.
Syosset, NY
September 1986

IBM Corporation
Federal Systems Division
Owego, NY
October 1986

Control Data Corporation
Government Systems Group
Minneapolis, MN
December 1986

Hughes Aircraft Company
Radar Systems Group
Los Angeles, CA
January 1987

ITT
Avionics Division
Clifton, NJ
September 1987

Rockwell International Corp.
Collins Defense Communications
Cedar Rapids, IA
October 1987

UNISYS
Computer Systems Division
St. Paul, MN
November 1987

Motorola
Government Electronics Group
Scottsdale, AZ
March 1988

General Dynamics
Forth Worth Division
Fort Worth, TX
May 1988

Texas Instruments
Defense Systems & Electronics Group
Dallas, TX
June 1988

Hughes Aircraft Co.
Missile Systems Group
Tucson, AZ
August 1988

Bell Helicopter
Textron, Inc.
Fort Worth, TX
October 1988

Litton
Data Systems Division
Van Nuys, CA
October 1988

GTE
Government Systems Corp.
Needham Heights, MA
November 1988

McDonnell Aircraft Co.
St. Louis, MI
January 1989

Information gathered from all BMP surveys is included in the Best Manufacturing Practices Management Information System (BMP-MIS). Additionally, a calendar of events and other relevant information are included in this system. All inquires regarding the BMP-MIS may be directed to:

Director, Naval Industrial Resources Support Activity
Attn: BMP-MIS System Administrator
Bldg. 75-2, Room 209, Naval Base
Philadelphia, PA 19112-5078
Telephone: (215) 897-6684